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ON THE TEMPERATURE OF THE INTERGALACTIC GAS

by

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SUMMARY

The question of kinetic temperature of the intergalactic gas in the evolutionary cosmological model is investigated in this paper. Various heating and cooling mechanisms are reviewed. It is suggested that explosions of galaxies and radiogalaxies constitute very effective sources of heating.

The liberation of heat is materialized mainly at energy dissipation of plasma oscillations, excited by anisotropic fluxes of cosmic rays. Taken into account is also the possible heating from relic sub-cosmic rays as a consequence of ionization losses in the intergalactic gas.

Solutions of the heat balance equation are given, which provide temperature variations of the intergalactic gas as the Metagalaxy expands.

The lower limit of possible gas temperature for the present epoch constitutes 10^5° K. The latter points to the incorrectness of the prevailing concepts that low gas temperature is indispensable in the evolutionary cosmology.

Analyzed also is the question of gas temperature in clusters of galaxies . The temporal course of temperature variation beginning from the consummation of the gravitational condensation in the clusters of galaxies or of radiogalaxy burst in them is revealed. At the same time, account is taken of the possible variety of cluster parameters.

A series of possibilities are discussed for the determination of the temperature of the intergalactic gas of the Metagalaxy from observations, and for making more precise the theoretical concepts connected with that temperature.

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* O temperature mezhgalakticheskogo gaza.

For the cosmology and cosmogony, such parameters as the density and the temperature of the intergalactic medium are of essential significance. It apparently follows from observations within the framework of isotropic cosmological models based upon the Einstein equation without the Λ - term [1] that the average density of the intergalactic matter constitutes

$$\rho \gtrsim \rho_k = 3H^2/8\pi G \simeq 2 \cdot 10^{29} \text{ g/cm}^3, \text{ [**]}$$

where $H \simeq 100$ km/sec , Mnc is the Habble constant.

At the same time, the mean density, linked with galaxies, is usually taken equal to $\rho_g \simeq 5 \cdot 10^{-31}$ g/cm^3 [2]. Therefore, starting from the indicated cosmological scheme it follows that we should consider the space as filled with matter, most likely diffusive, with average density some 20 to 50 times greater than ρ_g * .

Alongside with this, the character of intergalactic gas distribution is undetermined. In principle, the gas may be mostly localized in clusters of galaxis (nebulae), and if its mass is tens of times greater than that of galaxies, we would have $\rho \sim \rho_K$ without the assumption of existence of intergalactic gas background. The alternate possibility is the more or less uniform distribution of gas (with $\rho \sim \rho_K$) in the space between clusters of galaxies (the increased gas concentration inside the clusters is at the same time quite admissible in fairly broad limits). Precisely this possibility appears to us as being the most probable. Astronomical observations of the latest years have pointed to the existence of young galaxies and revealed the variety of the intergalactic condensation and so forth (see [5, 6]),which is evidence of the continuing formation process in the intergalactic medium of new structural units. At the same time, the metagalactic gas with a density exceeding a great deal the average density linked with galaxies, is a natural reservoir for the formation of new systems [7 — 10].

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* Here we set aside the possibility that the density ρ is linked with the neutrino [3] or with invisible collapsed masses [4].
[**] [The formula is reproduced exactly as in the original text; however, there is incompatibility between the formula and the following line].

According to the latest measurements [11], the concentration on neutral hydrogen in the intergalactic space is $n_H \leq 2.6 \cdot 10^{-5}\ cm^{-3}$ and, alongside with this, $n_H \leqslant 3.9 \cdot 10^{-8}\, T_S$, where T_S is the spin temperature of hydrogen *. There exists the opinion [13] that, within the framework of the evolutionary cosmology, the temperature at present is $T \simeq 1^{\circ} K$ **. Hence it would follow that the gas is not ionized,

$$T_S \sim T \sim 1^{\circ} K \ [11] \quad \text{and} \quad n_H \leqslant 10^{-7}\ cm^{-3} \ (\rho \leqslant 1.6 \cdot 10^{-31}\ g/cm^3).$$

that is, a direct contradiction would take place with the above-mentioned estimate $\rho \sim \rho_K$.

However, the conclusion of the necessity of having a low kinetic gas temperature in the evolutionary cosmology in our epoch is incorrect, as will be shown below. Indeed, the presence of specific heating sources of the intergalactic medium, such as the dissipation of energy of plasma oscillations excited by anisotropic fluxes of cosmic rays at bursts of galaxies and the ionization losses of cosmic and subcosmic rays, regardless of "hot" and "cold" variants of the initial stage of expansion [16], will lead to a rather high kinetic gas temperature and its practically total ionization. A rough estimate of the expected temperature of the intergalactic gas (which will be made more precise below when account is taken of the important effect of inertia in temperature settling) may be already obtained from the condition of approximate equality if densities of the inner gas energy nKT, the kinetic energy w_{kin} and the energy of cosmic rays w_{cr}:

$$nkT \sim w_{kin} \sim w_{cr} \qquad (1)$$

According to available estimates [17], the energy density of the injected cosmic rays $w_{cr} \sim 10^{-15} \div 10^{-17}\ erg/cm^3$. Hence, at utilization

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* A new method of estimating the density of the intergalactic neutral gas has been recently proposed [12]; it is based upon the investigation of resonance line Mg II absorption, from the emission shells of quasars. Unfortunately, the substantial uncertainty of Mg concentration (as well as other elements) in the intergalactic medium hinders a reliable estimate of the upper limit of hydrogen concentration over such a path.

** Analogous representations of low kinetic temperature of intergalactic gas are rather widespread [see for example 14, 15].

of (1) it would follow that the kinetic temperature of the intergalactic gas (with a concentration of protons $n \sim 10^{-5}\ cm^{-3}$) is

$$T \sim 10^5 \div 10^6\ {}^\circ K. \tag{2}$$

Note that the ideas of the importance of ionization losses of subcosmic rays for the heating of the intergalactic medium are included in [18] where, however, the detailed calculations were not conducted. We shall analyze below within the framework of the evolutionary cosmological model the question of thermal regime (including various heating and cooling mechanisms) and of temperature of the intergalactic gas outside, as well as inside the clusters of galaxies.

#1. - THERMAL REGIME IN THE INTERGALACTIC MEDIUM

The heat balance equation for the intergalactic gas has the form

$$L^+ - L^- = \frac{\rho R T}{\mu} \frac{d}{dt} \ln \frac{T^{\frac{1}{\varkappa - 1}}}{\rho} \tag{3}$$

Here L^+ and L^- are respectively the energy inflow and outflow in a unit of time, related to the unit of gas volume. The correlation (3) stems from the fundamental thermodynamic equality

$$\frac{L^+ - L^-}{\rho} = \frac{dQ}{dt} = C_v \frac{dT}{dt} + p \frac{d^{1}/\rho}{dt}, \tag{4}$$

where the pressure $p = \rho T R/\mu$, the specific heat capacity $C_v = R/\mu(\varkappa - 1)$, $\varkappa = C_p / C_v$ and μ is the molecular weight. By their sense the correlations (3) and (4) refer to a quiescent gas, that is, they are valid in the associated system of reading.

Let us consider the possible sources of heating and cooling in the conditions of the intergalactic medium.

1. - Sources of Heating

The specific peculiarity of the intergalactic medium is the insignificant role of radiation as a source of ionization and excitation of atoms of the intergalactic gas (perhaps with the exclusion of immediate vicinities of galaxies).

Under these conditions, the atoms are ionized by the electron impact, and, at the same time, the time of electron and ion temperature equalization

$$\tau_{el} \sim \frac{m_i}{m} \tau_e \; \frac{m_i (kT_e)^{3/2}}{m^{1/2} ne} \sim 10 \, \frac{T^{3/2}}{n} \text{ sec.}$$

is substantially less than all the time characteristics encountered below. As to the sources of heating, they can be the ionization losses of cosmic rays and sub-cosmic rays (fast nonrelativistic particles, practically protons with kinetic energy $E_k < 10^8 - 10^9$ ev), and also the conjunction of events linked with bursts of galaxies. Let us pause at each of these sources separately.

a) Ionization Losses of Subcosmic and Cosmic Rays.

The investigations, conducted on the ground, do not provide indications on the presence of a large flux of subcosmic rays. However, such types of measurements do not establish the absence of subcosmic rays in the interstellar medium, inasmuch as these particles might be unable to reach the terrestrial orbit on account of the presence of the "solar wind" and of its consequences. In the conditions of intergalactic medium, where the ionization losses are particularly small, the presence in the current epoch of significant flux of subcosmic rays is fairly probable. The energy liberated per unit of time by a nonrelativistic subcosmic particle at its motion in an ionized hydrogen constitutes [17]

$$\frac{dE}{dt} = 7.62 \cdot 10^{-9} \left(\frac{2m_p c^2}{E_k}\right)^{1/2} \left\{ \ln \frac{E_k}{m_p c^2} - \ln n^{1/2} + 38.7 \right\} n \text{ ev/sec} \quad (6)$$

and, consequently, the heating conditioned by subcosmic rays is

$$L^+_{i,\, scr} = \left(\frac{dE}{dt}\right) N_p = 6.7 \cdot 10^{-22} n \frac{w_{scr}}{E_k^{3/2}} \left\{ \ln \frac{E_k}{m_p c^2} - \ln n^{1/2} + 38.7 \right\} \text{erg/cm}^2 \cdot \text{sec} \quad [7]$$

Here N_p is the concentration of fast nonrelativistic protons with energy E_k in ergs and w_{scr} is their energy density in erg/cm^3.

It is hardly reasonable to estimate the energy density w_{scr} as being greater than that of cosmic rays, w_{cr}. According to [17], $w_{cr} < 10^{-14}$ erg cm^3 and it is probable that $w_{cr} \sim 10^{-15} \div 10^{-17}$ erg/cm^3.

Assuming for orientation that $w_{scr} \simeq w_{cr} \simeq 10^{-15}$ erg/cm^3 and $E_k \simeq 3 \cdot 10^7$ev , we obtain

$$L^+_{i,\,scr} = 7.1 \cdot 10^{-29}\, n \left\{1 - 0.032\, \ln n\right\} \text{ erg/cm}^3 \cdot \text{sec;}$$

it is more practical to utilize the approximate formula

$$L^+_{i,\,scr} \simeq 8.0 \cdot 10^{-29} n \ \text{ erg/cm}^3\,\text{sec} \qquad (8)$$

(with an approximation to 2 — 5% in the region $n = 10^{-3} \div 10^{-6}$ cm^{-3}).

The ionization losses from relativistic cosmic particles are, to the contrary, neglectingly small (at contemporary epoch). Indeed, for relativistic protons the losses constitute [17]:

$$-\frac{dE}{dt} = 7.62 \cdot 10^{-9}\left\{\ln 2\left(\frac{E}{m_pc^2}\right)^2 - \ln n + 73.1\right\} n \text{ ev/sec;} \quad m_pc^2 \ll E \ll \frac{m_p^2}{m}c^2$$

and the heating linked with it is

$$L^+_{i,\,cr} = 1.22 \cdot 10^{-20}\frac{w_{cr}}{E}\left\{\ln 2\left(\frac{E}{m_pc^2}\right)^2 - \ln n + 73.1\right\} n \quad \text{erg/cm}^3\,\text{sec}$$

which, at $w_{cr} = 10^{-15}$ erg/ cm^3, $E = 5 \cdot 10^9$ev $= 8 \cdot 10^{-3}$ erg, gives

$$L^+_{i,\,cr} \simeq 1.2 \cdot 10^{-31} n \ \text{ erg/cm}^3\,\text{sec} \qquad (10)$$

Note that the dissipation of the electron countercurrent, occurring at motion of cosmic rays in the intergalactic plasma owing to its high conductivity, leads also to gas heating [19, 20]. The density of the corresponding Joule losses constitutes

$$L^+_J = \frac{j^2}{\,} = \frac{\left(\frac{1}{3}ecN_{cr}\right)^2}{0.9 \cdot 10^8 T^{3/2}} \ln\left(300\frac{T}{n^{1/3}}\right) \simeq 3 \cdot 10^{-15}\left(\frac{10^6}{T}\right)^{3/2}\left(\frac{w}{E}\right)^2 \text{ erg/cm}^3\,\text{sec} \quad (11)$$

Even for subcosmic rays with $E_k = 3 \cdot 10^7$ ev and $w_{scr} = 10^{-15}$ erg/cm^3 the heating

$$L^+_J \simeq 1 \cdot 10^{-36}\left(\frac{10^6}{T}\right)^{3/2} \text{ erg/cm}^3 \text{ sec}$$

is quite small by comparison with (8), and becomes substantial only at $T \lesssim 10^4\,^\circ K$.

c) Bursts of Radiogalaxies.

Bursts of radiogalaxies and galaxies must constitute effective sources of heating for the intergalactic gas. Fluxes of hot gases may be ejected into the surrounding space at bursts and significant quantities of relativistic and subcosmic particles will be escaping into it; their friction with the intergalactic medium must lead to its heating. The temperatnre increase of the intergalactic gas will also contribute to the dissipation of part of the burst energy in shock waves. Let us examine the heating mechanism at further length.

In conditions, when the flux of cosmic rays, ejected during the burst, is anisotropic (and this must be the case in a certain region near the galaxies ejecting them), there appears, besides the usual ionization losses, an additional, quite effective mechanism of losses linked with the beam instability. In order to conduct a numerical evaluation, let us assume that the beam of particles (charge e, mass M, concentration N_s) moves along the magnetic field (or in conditions, when the field's influence is insignificant). Let the mean particle velocity be v_s, and the scattering of velocities near $v_s - v_{T_s}$ (to be specific, we estimate that the distribution function of particles in the beam has the form

$$f(v) = N_s\left(\frac{M}{2\pi kT}\right)^{1/2} \exp -\left[\frac{(v - v_s)^2}{2\,T_s}\right], \quad \left(v_{T_s}^2 = \frac{kT_s}{M}\right).$$

The plasma frequency for thr beam is

$$\omega_s = (4\pi e^2 N_s / M)^{1/2} = 5.64 \cdot 10^4 (N_s m/M)^{1/2},$$

and the plasma frequency of the medium penetrated by the beam is

$$\omega_o = (4\pi e^2 n_e / m)^{1/2} = 5.64 \cdot 10^4 n_e^{1/2}.$$

At $n_e \sim 10^{-5}\,cm^{-3}$, even in conditions of intergalactic space the frequency $\omega_o \sim 10^2\,sec^{-1}$, that is, the oscillation period $\tau_o = 2\pi/\omega_o \sim 10^{-1}$ sec is neglectingly small by comparison with the other characteristic times. For a proton beam (or for electrons with total energy $E \sim Mc^2 \sim 10^9$ ev), at $N_s \sim 10^{-13}\,cm^{-3}$ the frequency $\omega_s \sim 3 \cdot 10^{-4}$ and $\tau_s = 2\pi/\omega_s \sim 10^4$ sec. Under the indicated conditions the beam generates plasma waves, whose intensity accrues according to the law $e^{\gamma t}$ (see, for example, [21]), where

../..

$$\gamma = \frac{\pi}{2}^{1/2} \frac{\omega_s^2 \omega_0 (v_s - v_\varphi)}{q^2 v_{T_s}^2} \exp \frac{(v_\varphi - v_s)^2}{2 v_{T_s}^2}$$

Here $v_\varphi = \omega/q$, $\omega^2 = \omega_0^2 \; 3 v_{T_0}^2 q^2$, $v_{T_0} = (kT/m)^{1/2}$ is the electron temperature in plasma (without beam) and q is the wave vector of emitted waves with a frequency $\omega \sim \omega_o$. The wave accretion obviously takes place only at $v_\varphi < v_s$; besides, according to the conditions of the conclusion, we must estimate that

$$3 v_{T_o}^2 q^2 \ll \omega_o^2$$

or, at rough estimates $3 v_{T_o}^2 q^2 \lesssim {}_o^2$. Hence it is clear that

$$q_{max} \sim \omega_o / v_{T_o} \sim 10^{-6} \text{ and } q_{min} \sim \omega_o / v_s \sim 10^{-8},$$

(at $\omega_o \sim 10^2$, $v_s \sim 10^{10}$, $v_{T_o} \sim 10^8$, $T \sim 10^5 \, {}^o K$).

We shall estimate that in the beam we have $v_s \sim v_{T_s} \sim c \sim 10^{10}$ cm/sec. Then, at the above-admitted values and $q = q_{min}$ the increment is

$$\frac{\omega_s^2 \omega_o}{q_{min}^2 v_{T_s}^2} \sim 10^{-9},$$

or the characteristic time of oscillation accretion is $1/\gamma \sim 30$years (at $q \sim q_{max}$ time it will be $1/\gamma \sim 3 \cdot 10^5$ years, but the character of field accretion is determined precisely by the last value of γ). Since the concentration of cosmic rays in ejections is probably exceeding significantly 10^{-13} cm^{-3}, the true increment of accretion may be even higher*

The plasma oscillations in the beam will accrue so long as this accretion will not be limited by nonlinear effects and reverse action of oscillations on the beam itself. In particular, strong beam blurring would be sufficient (isotropization beam) for the increment γ to fall abruptly.**

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* The above estimate of γ is evidently rather rough. Nevertheless, by the strength of great "reserve" (the increment γ is great) the conclusion drawn of the effectiveness of plasma wave generation appears to be quite convincing.

** The question of isotropization of cosmic rays as a result of generation by them of plasma waves is also discussed in recent works [30, 31].

Generally speaking, similar reverse action will set in only in conditions when the energy of plasma oscillations is comparable with the energy of the beam. By the same token we reach the assumption that the injection of cosmic and subcosmic rays into the intergalactic space must, visibly, be attended by an effective buildup of plasma oscillations in the intergalactic plasma, the energy density of these oscillations being at the same time $w_o \sim w_{cr} + w_{scr}$.

Subsequently, when taking into account collisions and the nonlinear interaction of plasma waves, the plasma oscillations pass to heat, that is, they lead to gas temperature increase.

The "thermalization" time of plasma oscillations is of the order of the inverse number of oscillations, that is, $\sim [5.5 nT^{3/2} \ln(220n^{-1/3})]^{-1}$, which, at $n \sim 10^{-5}\,cm^{-3}$ and $T \sim 10^{6\,o}\,K$ constitutes $\sim 3 \cdot 10^4$ years.*

The heating conditioned by radiogalaxy bursts, may be estimated for the current epoch starting from the contemporary energy density of cosmic rays (see also [17], p. 264),

$$w_{cr} \simeq \langle P N_{rg} \rangle T_{Mg},$$

where N_{rg} is the contemporary concentration of radiogalaxies with mean explosion power P and $T_{Mg} = 3 \cdot 10^{17}$ sec. is the age of the adopted cosmological model. Hence, the heat liberation $L_g^+ = w_{cr}/T_{Mg}$ constitutes, at utilization of the above discussed estimate, $w_{cr} \simeq 10^{-15}$ erg/cm,

$$L_g^+ = 3 \cdot 10^{-33}\,erg/cm^3\,sec. \qquad (12)$$

2. - Sources of Cooling

In intergalactic medium conditions, the cooling takes place owing to hydrogen de-excitation at free-free transitions and at recombinations. Aside from hydrogen, the electron impact may be instrumental in exciting also the low-lying levels of a series of elements, with subsequent de-excitation, which, as is well known, is the basic mechanism of zones H II cooling of the interstellar medium.

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* Damping of plasma waves possibly takes place at distances notably lesser than those between bursting sources. In this case the heating of the intergalactic medium will be spatially nonuniform.

The question of the existence of heavy elements in the intergalactic space remains open. However, the sharp distinction in the chemical content of the stars of type I and II population (more than 100 times) points the fact that the formation of stars at earlier stages of Galaxy condensation had taken place in a medium poor in heavy elements.

We may assume for the upper limit of heavy element concentration in the intergalactic medium the concentration of these elements in the oldermost stars of the Galaxy (the relative concentration of elements heavier than helium

$$Z_{Mg} \sim Z_{g,II} = 10^{-2} Z_{g,I})^{*}$$

At $T \sim 10^5 \div 10^6$ °K the cooling of the intergalactic medium of heavy elements of such a concentration is several times less than the cooling of a purely hydrogen medium and that is why it can be omitted at the estimate of intergalactic gas temperature.

Therefore, the heat transfer L^- in the equation (3) may be represented by the sum of two terms

$$L^- = L^-_{ff} + L^-_{fb}$$

The energy, emitted at free-free transitions, constitutes (see, for example, [9])

$$L^-_{ff} = \int_0^\infty \frac{64\pi^2 e^6\, gn \cdot n_p}{3mc^3\,(6\pi mkT)^{1/2}}\, e^{-\frac{h\nu}{kT}}\, d\nu \simeq 1.4 \cdot 10^{-27} T^{1/2} n^2 \ \text{erg/cm}^3 \ \text{sec} \equiv \equiv a \cdot T^{1/2} \cdot n^2 \qquad (13)$$

where we admitted $n_e = n_p = n$, in agreement with the fact, that the main contributor of free electrons is hydrogen.

The deexcitation at recombination is given for all levels by formula (9).

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* If at bursts of galaxies there takes place a chemical synthesis of elements, their filling the metagalactic medium takes place during the times comparable with the cosmological scale, that is, rather slowly (the mean distance between galaxies is $\sim 10^{25}$ cm, the propagation velocity $v \sim 1000$ km/s. and $\tau \sim 10^{17}$ sec.).

$$L^-_{fe} = 4\pi \sum_{n=1}^{\infty} \frac{1}{n^3} \int_{\nu_n}^{\infty} \frac{2^7 \pi^4 e^{10} m g_n}{c^3 h^2 (6\pi m k T)^{3/2}} e^{-\frac{h\nu - \chi_n}{kT}} n_e n_p \simeq$$

$$\simeq 5{,}4 \cdot 10^{-22} T^{-1/2} n^2 \text{ erg/cm}^3 \text{ sec} = \beta T^{-1/2} n^2 \qquad (14)$$

~~#~~ 2. - TEMPERATURE OF THE INTERGALACTIC MEDIUM IN THE METAGALAXY

The principal peculiarity of the intergalactic gas outside the clusters is its participation in the cosmological expansion of the Metagalaxy. Because of the expansion, the kinetic temperature drops, and this cooling constitutes the decisive process for later stages of expansion.

Because of the smallness of the pressure $p = \rho T R/\mu$ by comparison with the total energy density $\varepsilon = \rho c^2$, the variation of density with the time in the isotropic model may be described by the exact solution of the Einstein equation for a uniform isotropic universe with $p = 0$. For our objectives it is sufficient to utilize the solution valid in the plane metrics ($\rho = \rho_k$) and with not too bad a precision at $\rho \sim \rho_k$:

$$\rho = \rho_0 T^2_{Mg} t^{-2} \qquad (15)$$

where ρ_0 is the density at the moment of time $t = T_{Mg}$.

For practical puroposes we shall pass in (3) from differentiation over time to differentiation over density, having substituted, according to (15), $d/dt = -2 (\rho_0^{1/2} T_{Mg})^{-1} \rho^{3/2} \, d/d\rho$. As a result, instead of (3), we shall have

$$L^+ - L^- = -\frac{2R}{\mu} (\rho_0^{1/2} T_{Mg})^{-1} T \rho^{5/2} \frac{d}{d\rho} \ln \frac{T^{\frac{1}{\varkappa - 1}}}{\rho} \qquad (16)$$

Either terms may predominate at various stages of expansion, entering in (16). Let us compare the expression responding to cooling as a consequence of radiation (13) - (14)

$$L^-_{ff+fe} = (5{,}2 \cdot 10^{20} T^{1/2} + 2{,}0 \cdot 10^{26} T^{-1/2}) \rho^2 \text{ erg/cm}^3 \text{ sec} \qquad (17)$$

with the term responsible for the cooling on account of expansion

$$L^{-}_{exp} = P\rho \frac{d1/\rho}{dt} = \frac{2\mathcal{R}}{\mu}\left(\rho_o^{1/2} T_{Mg}\right)^{-1} \rho^{3/2} T \qquad (18)$$

Assuming $\mu = 1/2$ and admitting that $t = T_{Mg} = 3\ 10^{17}$ sec, the density of the intergalactic gas will be $\rho_o = \rho_k = 2 \cdot 10^{-29}$ g/cm^3, we have

$$L^{-}_{exp} = 2{,}5 \cdot 10^{5} \rho^{3/2} T \ \text{erg/cm}^3\ \text{sec} \qquad (18\,a)$$

It is easy to see, that in the epoch when $\rho/T^3 \gtrsim 10^{-42}$, or at $T \sim 10^5$ °K, when $\rho \gtrsim 10^{-27}$ g/cm^3, cooling prevails on account of deexcitation. To the contrary, at fulfillment of the inverse inequality, cooling on account of expansion is achieved. Let us analyze these situations separately by considering first the particular solutions of the equation (16).

I. Cooling by Radiation in the Absence of Sources of Heating

At $\rho \gtrsim 10^{-27}$ g/cm^3, cooling on account of expansion is immaterial. In this case the variation of medium's temperature, neglecting the heating, is described by a simple equation taking into account only the cooling at the expense of radiation

$$\frac{3}{2}\gamma\rho^{1/2}\frac{dT}{d\rho} - \alpha T^{1/2} - \beta T^{-1/2} = 0 \qquad (19)$$

The numerical values of the coefficients are here as follows :

$$\alpha = a m_H^{-2} = 5{,}2 . 10^{20} \qquad \beta = b\, m_H^{-2} = 2{,}0 . 10^{26}$$

$$\gamma = \frac{2\mathcal{R}}{\mu}\left(\rho_o^{1/2} T_{Mg}\right)^{-1} = 2{,}5 . 10^{5}$$

The solution of the equations (19) has the form

$$\left(\frac{\alpha}{\beta}T\right)^{1/2} - \operatorname{arctg}\left(\frac{\alpha}{\beta}T\right)^{1/2} - \frac{2\alpha^{3/2}}{3\gamma\beta^{1/2}}\rho^{1/2} = const$$

This solution offers some interest when analyzing the gravitational condensation leading to the formation of nebula clusters.

II.- Cooling on Account of Expansion in the Presence of Sources

Let us consider now the later stages of expansion, when the cooling by radiation becomes small and the determinant role is played by cooling on account of expansion. It is evident that if at the stage, when expansion becomes the prevailing mechanism of cooling, the temperature is insufficiently high, a continuing action of heating sources, considered in para. 1 may become important also. In this case the equation (16) takes the form

$$\frac{3}{2}\gamma\rho^{5/2}\frac{dT}{d\rho} - \gamma\rho^{3/2}T + L^{+} \quad 0$$

The heat liberation L^{+} constitutes the sum of several terms, the relative contribution of which varies as the expansion progresses. Let us bring forth the expression for them as a function of time, or, in our denotations, as a function of density

a) Ionization losses of Subcosmic Rays

According to (7), $L^{+}_{i,scr} \sim w_{scr}\, E^{-3/2}\, n$.

In the course of expansion the energy of relic subcosmic particles varies as $\rho^{1/3}$ in correspondence with the well known law of decrease $\sim R^{-1}$ of the impulse of a particle moving in an expanding Freedman universe. The concentration of particles varies as ρ; neglecting the variation of logarithmic terms in [7], and utilizing (8), we obtain

$$L^{+}_{i,scr} = 1.0 \cdot 10^{-33}\,(\rho/\rho_0)^{5/3}\,\mathrm{erg/cm^3\,sec} = \delta\rho^{5/3} \quad (23)$$

where, here and subsequently, $\rho_0 = \rho_k = 2 \cdot 10^{-29}$ g/cm^3 implies a fixed epoch, for which the contemporary is taken.

The ionization losses of relativistic particles and the heating conditioned by them, vary in time in a different manner. For an invariable number of relativistic particles their concentration decreases as ρ, the energy decreases as $\rho^{1/3}$, and the energy density as $\rho^{4/3}$; neglecting the variation of logarithmic terms, we shall obtain from (9) and (10) :

$$L^{+}_{i,\,cr} = 1.5 \cdot 10^{-36} \, (\rho/\rho_o)^2 \, \mathrm{erg/cm^3\,sec} \equiv \varepsilon \rho^2 \qquad (24)$$

It may be seen from (23) and (24) that, although in previous epochs the relative role of relic cosmic rays (particles having formed at formation stage of the main mass of galaxies) was higher from the standpoint of heating than it now is, the prevailing value for the heating then was also imparted to subcosmic particles.

b) Intrusion of Cosmic Ray Fluxes during Bursts of Galaxies

Assuming that the evolutionary effect in the power of bursts of galaxies is absent and that the heating of the unit of volume by ejected fluxes of cosmic rays, by shock waves and incandescent gases varies only at the expense of Metagalaxy expansion, we have, taking into account (12):

$$L^{+}_{g} = 3 \cdot 10^{-33} \, \rho/\rho_o \, \mathrm{erg/cm^3\,sec} \equiv \xi \rho \qquad (25)$$

It is appropriate to consider the temperature variation of the intergalactic gas in the presence of heat liberation in two variants: taking into account separately the heating conditioned by ionization losses of relic subcosmic rays (variant IIa) and the heating conditioned by continuing galaxy bursts in the process of consideration of the Metagalaxy (variant IIb).

IIa.- Heating of the Intergalactic Medium by Relic Cosmic Rays.

When accounting the ionization losses of subcosmic and cosmic rays (23)-(24), the temperature variation of the intergalactic medium is described by the equation

$$\frac{dT}{d} - \frac{2}{3}\frac{T}{} + \frac{2}{3\gamma}\left(\delta\rho^{-5/6} + \delta\rho^{-1/2} \right) = 0 \qquad (26)$$

The second term in parentheses, linked with the heating by relativistic particles, is preserved here, stemming from the fact that the coefficient δ in (23) is now less accurately known than ε in (24). The solution of the equation (26) has the form

$$T = \rho^{2/3}\left(\frac{4}{3}\frac{\delta}{\gamma}\rho^{-1/2} + 4\frac{\varepsilon}{\gamma}\rho^{-1/6} + const\right) \tag{27}$$

and, at substitution of the above admitted numerical values of γ, δ and ε, it may be written as follows :

$$T = \left(\frac{\rho}{\rho_0}\right)^{2/3}\left[\theta_1 + 6{,}0\cdot 10^4\left(\frac{\rho}{\rho_0}\right)^{-1/2} + 2{,}7\cdot 10^2\left(\frac{\rho}{\rho_0}\right)^{-1/6}\right] \tag{28}$$

The constant θ_1 is easily expressed through the value of temperature at a a certain fixed moment of time. Note that the solution of (27) may be utilized also in the case when at $t = T_{Mg}$ the density of the gas is $\varkappa\rho_0$, where $\varkappa$ takes account of the fraction of the gas component in the total density of the Metagalaxy, and $1 - \varkappa$ corresponds to the share of gas in clusters and uneasily observable forms of matter (neutrino, latent masses). In this case the right-hand part of (28) should be multiplied by $\varkappa^{3/2}$, as this clearly stems from (18), (23), (24).

II b. - Heating of the Intergalactic Medium at Bursts of Galaxies

In this case the variation of gas temperature is determined by the equation

$$\frac{dT}{d\rho} - \frac{2}{3}\frac{T}{\rho} + \frac{2\xi}{3\gamma}\rho = 0 \tag{29}$$

the solution of which is

$$T = \rho^{2/3}\left[\frac{4}{7}\frac{\xi}{\gamma}\rho^{-7/6} + const\right] \tag{30}$$

or, numerically, with the utilization of (25)

$$T = \left(\frac{\rho}{\rho_0}\right)^{2/3}\left[\theta_2 + 0{,}77\cdot 10^5\left(\frac{\rho}{\rho_0}\right)^{-7/6}\right] \tag{31}$$

If at $t = T_{Mg}$ the density of gas constitutes $\varkappa\rho_0$ and the energy density of cosmic rays is $w_{cr} = \chi \cdot 10^{-15}$ erg/ cm^3, the numerical coefficient in (31) should be multiplied by $\varkappa^{1/2}\chi$.

The course of gas temperature as the Metagalaxy expands is plotted in Figs 1 and 2 for several various values of temperature in the epoch $\rho = 2 \cdot 10^{-27}$ g/cm^3, when the cooling by radiation becomes immaterial, and this in accordance with the variants (28) and (31). Note that the moment of time responding to $\rho = 2 \cdot 10^{-27}$ erg/cm^3, is close to the epoch of formation of the main part of galaxy.

The curves are plotted for several values of energy density of cosmic rays in the contemporary epoch $w_{cr} = 10^{-14} \div 10^{-16}$ erg/cm^3, of which the most probable value is $w_{cr} = 10^{-15}$ erg/cm^3. Assigning ourselves a rather broad temperature interval $10^4 \div 10^6$ °K at the moment of time $\rho = 2\ 10^{-27}$ g/cm^3, we reach, at $w_{cr} = 10^{-15}$ erg/cm^3, to the value of temperature for the contemporary epoch, in all cases near $T \sim 10^5$ °K*.

Note that this temperature value of the intergalactic gas constitutes only the lower limit. Even in the absence of notable heating from galaxy bursts in the present epoch (for example, as a consequence of a strong evolutionary effect) gas might have been strongly heated (even to temperatures $T \gtrsim 10^7$ °K) early after consummation of the formation of the main part of the galaxy by cosmic rays ejected in this epoch. At subsequent cooling because of expansion, the temperature of the gas could not have dropped toward the present epoch below $\sim 10^6$ °K.

Making use of the obtained lower limit of temperature, we may conclude, in particular, that in the present epoch, at mean concentration of intergalactic gas $n \sim 10^{-5}$ cm^{-3}, the characteristic dimension of the uniformity cell in the intergalactic gas, having the order of Jeans instability wavelength $\lambda_J \simeq (\pi K T / m_H \gamma \rho)^{1/2}$, constitutes several megaparsec.

It may be seen from Figs. 1 and 2 that the heating induced by bursts of galaxies is particularly effective. In the final count, the temperature decrease because of expansion is reversed because of that heating, to rise of temperature; at the same time, so much the earlier that the initial temperature was lower. This temperature rise had probably a natural limit, for the evolutionary effect must apparently become significant for sufficiently great time intervals. In this case the heating of the inter-

* see infrapag. note next page.

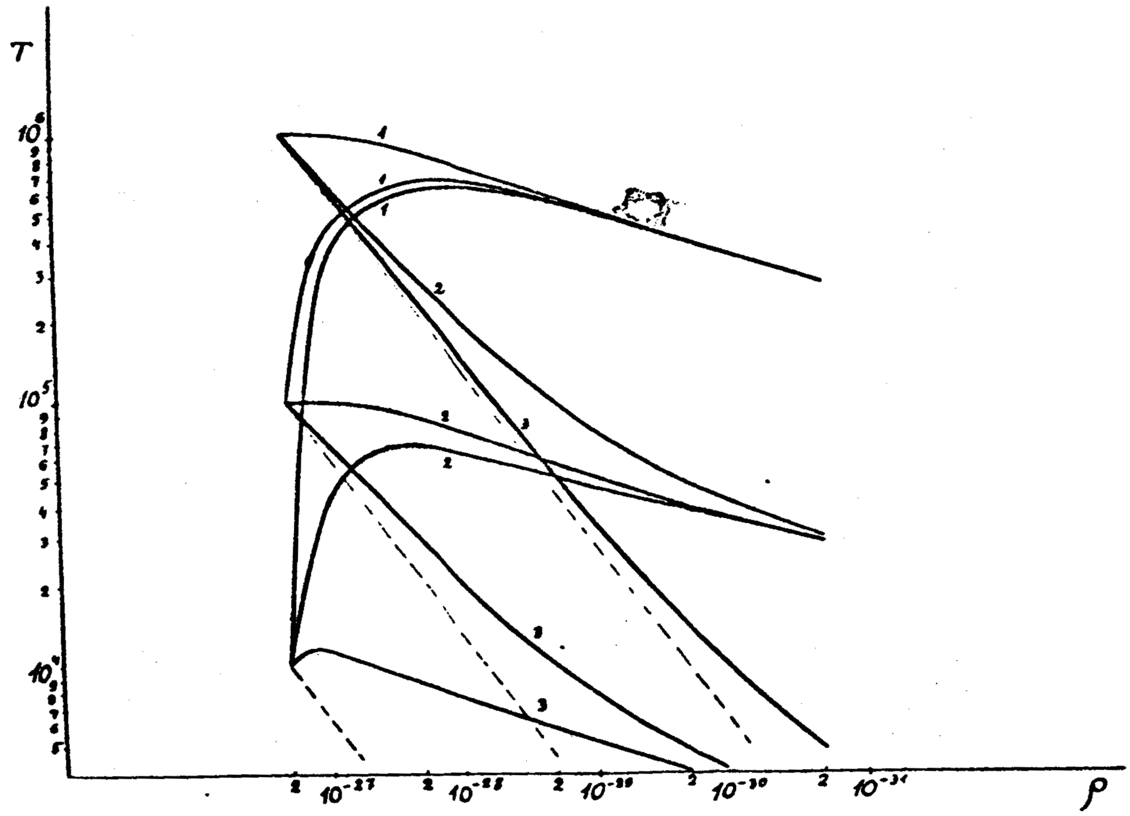

Fig. 1 TEMPERATURE VARIATION OF THE INTERGALACTIC MEDIUM AT EXPANSION OF THE METAGALAXY

[VARIANT II A]

1 — w_{cr} (T_{Mg}) = 10^{-14} erg/cm^3

2 — w_{cr} (T_{Mg}) = 10^{-15} erg/cm^3

3 — w_{cr} (T_{Mg}) = 10^{-16} erg/cm^3

---

* (From the preceding page)

The making more precise of the temperature of the intergalactic medium in the future will allow, in its turn, to make more precise the value of the energy of cosmic rays in the intergalactic space. But presently already the undertaken consideration in conjunction with the estimate of the minimum temperature of the intergalactic medium by X-ray data, dealt with below, is evidence against the possibility of assuming that $w_{cr} \sim 10^{-12}$ erg/cm^3 as this is sometimes estimated (see [17] and the reference literature presented there).

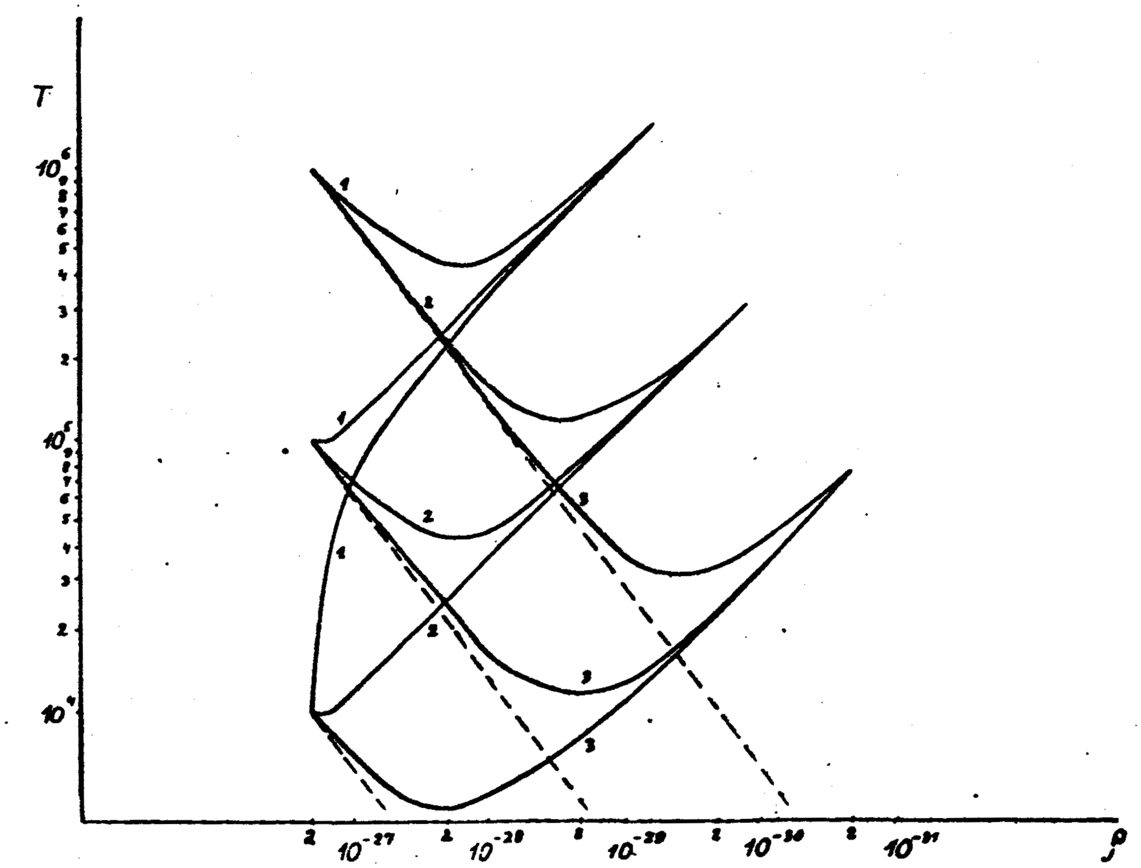

Fig. 2. - TEMPERATURE VARIATION OF THE INTERGALACTIC MEDIUM AT EXPANSION OF METAGALAXY

[Variant II B]

1 — w_{cr} (T_{Mg}) = 10^{-14} erg/cm^3

2 — w_{cr} (T_{Mg}) = 10^{-15} " "

3 — w_{cr} (T_{Mg}) = 10^{-16} " "

galactic medium drops notably while the temperature begins to decrease. At limit, when $L^{+} = L^{-} = 0$, it follows from (16) that

$$\frac{d}{d\rho} ln \frac{T^{\frac{1}{\varkappa-1}}}{\rho} = 0 \qquad (29)$$

whence

$$T \sim {}^{\varkappa-1} \qquad (30)$$

At $\varkappa = 5/3$ we have at the stage of free expansion $T \sim \rho^{2/3}$.

Even if $T \rightarrow 0$ at $\rho \rightarrow 0$, the gas remains practically fully ionized. Indeed, the settling time of equilibrium ionization is determined by recombination time and constitutes

$$t_{r} = 10^{3} T^{1/2} n^{-1} \text{ years.} \qquad (31)$$

On the other hand, the characteristic time of density variation is

$$t_{exp} = \rho / \left|\frac{d}{dt}\right| \simeq 5 \cdot 10^{9} \left(\frac{10^{-5}}{n}\right)^{1/2} \text{ years.} \qquad (32)$$

In the epoch, repsonding to $\rho = 2 \cdot 10^{-27}$ g/cm^{3}, we have $n \sim 10^{-3}$ cm^{-3} and $t_{exp} \simeq 5 \cdot 10^{8}$ years, and $t_{r} \simeq 10^{6} T^{1/2} \sim 10^{9}$ years (at $T \sim 10^{6}$ °K). In other words, in the epoch, when the cooling on account of expansion begins to prevail over the cooling as a consequence of radiation, the characteristic times t_{r} and t_{exp} are equalized. Assume now that even the heating is absent from the moment of time $\rho = 2 \cdot 10^{-27}$ g/cm^{3}. Then, in the following, we shall have $T \sim n^{2/3}$ and, this means $t \simeq 10^{7} n^{-4/3}$ years and $t_{exp} \simeq 10^{7} n^{1/2}$ years. Hence it may be seen that at further expansion, $t_{r} > t_{exp}$, that is, "freezing" of ionization takes place. Therefore, in spite of the fact that $T \rightarrow 0$, the gas remains ionized even in the absence of heat liberation.

But, if the gas were relatively cold and neutral at the outset, that is $T \sim 10^{4}$ °K, it may be seen from Fig. 2 that it could be ionized at subsequent heating by galaxy bursts and also by relic cosmic rays (see Fig. 1).

Note that the high ionization of the intergalactic medium leads to the fact, that in the process of formation of new structural units in the Metagalaxy, the magnetic field has probably a principal value (refer in particular to quasars [22 – 23]).

#3 . - TEMPERATURE OF THE INTERGALACTIC MEDIUM IN CLUSTERS

The above obtained data allow to tackle also the question of possible temperature of the intergalactic gas in clusters. Obviously, in this case the expansion of the medium, linked with the general evolution of the Metagalaxy, is absent.

It is well known that nebula clusters reveal a significant variety in the population, from multiple systems, including only a few terms, to general associations, including no less than tens of thousands of terms. In connection with this, the conditions in the intergalactic cluster medium must apparently substantially differ also. We shall limit ourselves here to considering clusters in stationary state. The correct spheroidal shape and the presence of notable concentration of galaxies toward the center , point to the stationary state in the course of cosmogonic terms in a substantial part of clusters. Apparently, gas density between galaxies, independent from time, should naturally be accounted for in such clusters, beginning from the epoch of gravitational condensation of the main part of galaxy clusters.

As formerly, the equation (3) is the starting point for the qualitative analysis of the heat balance of intergalactic cluster medium. Assuming in (3) that $\mu = 1/2$, $\varkappa = 5/3$, we have

$$3\,nk \frac{dT}{dt} = L^{+} - L^{-} \qquad (33)$$

The cooling L^{-} in (33) is determined for a given T only by the density of hydrogen atoms * and is given by formulas (13) and (14). The energy liberation L^{+} in cluster intergalactic gas apparently depends not only of the density of the gas, but is determined by the individual peculiarities of clusters, and first of all, by the existence in them at present and past of radiogalaxies, whose bursts might lead to substantial heating of the medium, as is shown by a simple estimate (see below).

For the computation of the minimum heating it is appropriate to examine the limit case, when heat liberation in gas cluster is determined by only a

* Although the chemical composition of the intergalactic medium in clusters possibly differs by a somewhat greater content Z of heavy elements by comparison with the intergalactic medium in the Metagalaxy, we limit ourselves, because of the uncertainty of Z, to accounting the cooling on H, similarly to what was done in #2.

single metagalactic "background". We shall concretely estimate that in (33) L^+ is due to the above considered ionization losses of subcosmic rays, that is, $L^+ = c\,n$, where the constant is given by formula (7). Then the gas temperature variation is described by the equation

$$3nk\frac{dT}{dt} = cn - (aT^{1/2} + bT^{-1/2})\,n^2 \tag{34}$$

where, according to (8), (13), (14), we postulate :

$$\begin{aligned} a &= 1.4\cdot 10^{-27} \\ b &= 5.4\cdot 10^{-22} \\ c &= 8.0\cdot 10^{-29} \end{aligned} \tag{35}$$

The solution of (34) has the form :

$$\frac{n}{3k}(t_1-t) = \frac{2}{a}\sqrt{T} + \frac{c}{a^2 n}\ln\left(aT + \frac{c\sqrt{T}}{n} + b\right) + \frac{\frac{c^2}{n^2} - 2ab}{a^2} \times \begin{cases} \frac{-2}{\sqrt{-\Delta}}\,\mathrm{Arcth}\,\frac{2a\sqrt{T}-\frac{c}{n}}{\sqrt{-\Delta}}, & \Delta<0 \\ \frac{-2}{2a\sqrt{T}-\frac{c}{n}}, & \Delta=0 \\ \frac{2}{\sqrt{\Delta}}\,\mathrm{Arctg}\,\frac{2a\sqrt{T}-\frac{c}{n}}{\sqrt{\Delta}}, & \Delta>0 \end{cases} \tag{36}$$

$$\Delta \equiv 4ab - c^2/n^2$$

The sign of Δ, determining the choice of either solution in (36), depends on **n**. For the numerical value of **c** taken in (35), we have $\Delta \gtrless 0$ at $n \gtrless 4.6\cdot 10^{-5}$ cm^{-3}.

The density of gas in clusters is unknown. However, it is quite probable, that as an average, this value is in any case less or of the order $10^{-3}\,cm^{-3}$. Indeed, according to [24] , the mean number of cluster centers is $\simeq 10^{-3}\,Mnc^{-3}$, and the mean volume corresponding to a single cluster is $\simeq 14\,Mnc^3$. Hence the part of the volume occupied by clusters, $\simeq 10^{-2}$ and the density of gas in clusters must, as an average, be in correspondence with $\rho_0 \simeq \rho_k \simeq 2\cdot 10^{-29}$, of the order

$$\bar{n} \lesssim 10^{-3}\ cm^{-3} \tag{37}$$

Inasmuch as the true concentration of gas in a separate cluster must differ from the upper limit of (37), we shall consider several different values of **n**, when analyzing numerically the solution of (36).

The course of gas temperature variation is presented in Fig. 3 :

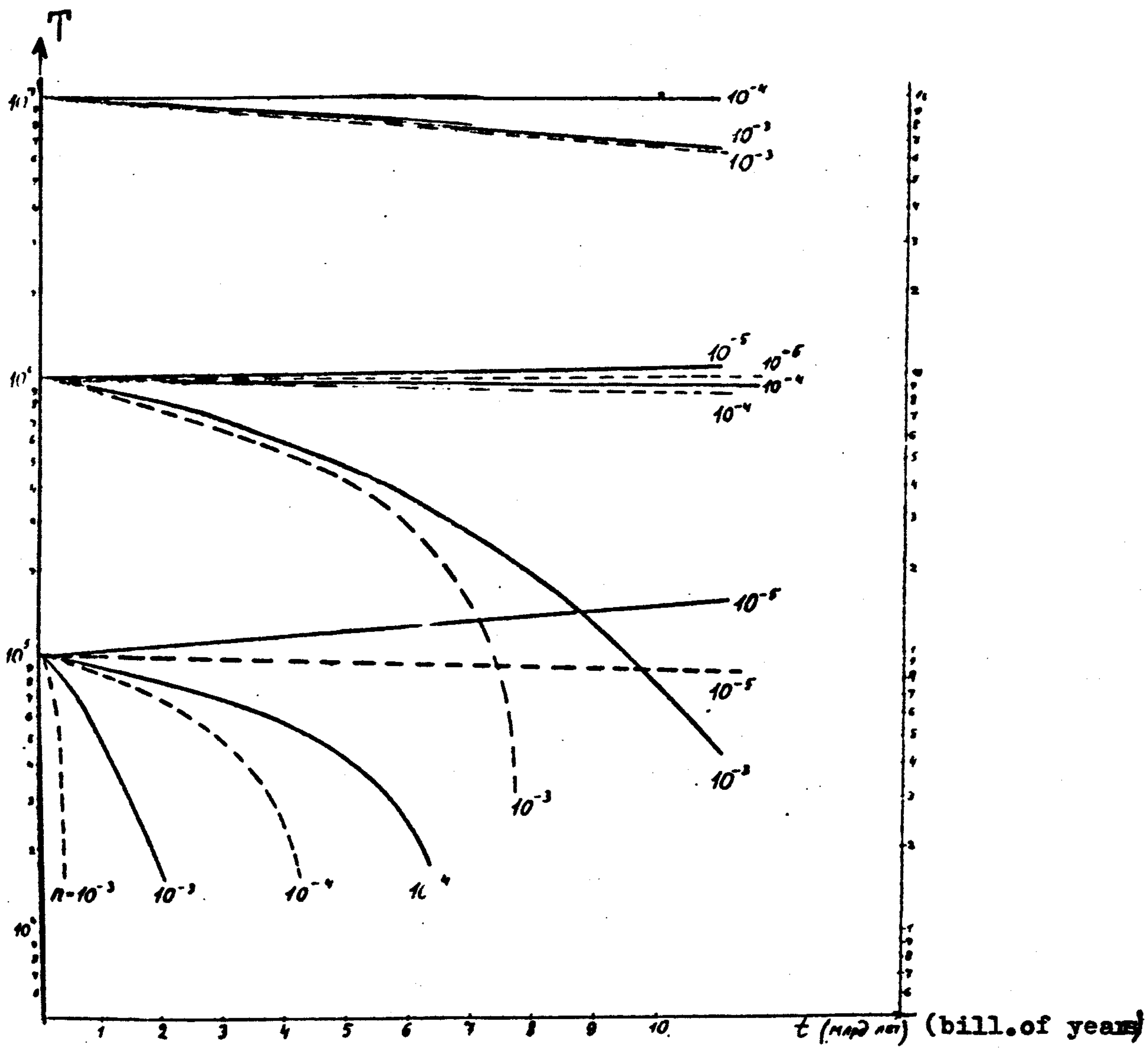

Fig. 3. - Temperature of the Intergalactic Medium in the Clusters of Galaxies

The variation of T in the absence of heating sources is plotted by dashes; it is found from the equation (36) at $c = 0$:

$$\frac{n a^{3/2}}{6 k^{1/2}} (t_1 - t) = \left(\frac{a}{b} T\right)^{1/2} - \operatorname{arc\,tg} \left(\frac{a}{b} T\right)^{1/2} \qquad (38)$$

For the initial condition defining the constant t_1, the temperature at the moment of time $t = 0$ is assigned, for which any characteristic epoch for the cluster may serve, for example, the consummation in it of condensation of the basic mass of galaxies or burst of radiogalaxy. The range of initial temperatures, taking account of the possible variety of conditions at $t = 0$, is visibly included in the limits $10^5 - 10^7$ °K. But if the bursts of galaxies were absent in the cluster, the boundary of this interval must be diminished inasmuch as the cooling of the gas from $T \sim 10^6$ °K takes place as is seen in Fig. 3, even at 10^{-3} cm^{-3}, that is, quite slowly, and this should hinder the condensation of galaxies in earlier epochs [14].

It may be estimated from (34) and (35) that at $n \sim 10^{-3} - 10^{-4}$ cm^{-3} the inequality $L^- > L^+$ takes place and the heating only slows down the rate of T decrease. However, this slowing down is significant and constitutes billions of years, as this may be seen from Fig. 3. As for the small gas concentrations in clusters, the heating is stronger than the cooling ($L^+ > L^-$), and the temperature of the gas also rises with time. A burst of a radiogalaxy in the given cluster may lead to very high gas temperatures owing to the action of heating mechanisms noted in # 1, linked with the instability of anisotropic ejections of cosmic rays, of hot gas fluxes, of shock waves and so forth. The order of temperature, to which the cluster gas is heated, may be estimated from the conditions

$$W_{cr} \sim n k T V,$$

where W_{cr} is the energy cosmic rays ejected by the radiogalaxy at its burst in a cluster of volume V. For a diamater of the cluster ~ 3 mps and $W_{cr} \sim 10^6$ ergs, the temperature $T \sim \frac{10^2}{n}$ °K, that is at $n \sim 10^{-4} \div 10^{-5}$ cm^{-3} $T \sim 10^6 \div 10^7$ °K. Inasmuch as, according to (31), the recombination time in the gas constitutes near 10^8 years even at $n = 10^{-3}$ and $T \sim 10^4$ °K, which is much more than the characteristic time of energy liberation at the burst, $\tau_p \sim 10^6$ years, the burst in the intergalactic gas of a cluster is practically equivalent to the action of an instantaneous heating source, leading to a high value of temperature. For certain clusters it becomes possible, owing to the burst, to have a heated gas outflow into the intergalactic space.

The detection by direct or indirect method of ionized gas in a cluster still does not determine unambiguously the origin of heating. To the contrary, the existence of neutral hydrogen, with concentration $n_H \sim 10^{-3}$ in the cluster would be evidence of the absence of high gas temperature in the past, in view of slow cooling of that gas from temperatures $T \sim 10^6 {}^\circ K$ and higher. This would mean the absence in the cluster of burst or penetration from without of subcosmic rays(from the general metalagactic reservoir). The latter might take place at closed state of lines of force of the magnetic field in cluster, as this is assumed in the "expanded model of the origin of cosmic rays [24]. Evidently, investigations of the intergalactic gas in clusters offer interest for that reason, and also for ascertaining the character of the magnetic field in galactic clusters.

It may be assumed that the decrease with time of intergalactic gas' temperature is, as an average, slower for the gas of clusters than for the expanding metagalactic gas background. (This is particularly so at great evolutionary effect in bursts of radiogalaxies). In the final count, and for certain clusters already in the contemporary epoch, we shall arrive at the pattern of hot regions included in the background of a colder gas.

CONCLUDING REMARKS

The above expounded ideas show that in the evolutionary model of the Universe the intergalactic gas may have and in all probability has, at continuous distribution with average density $\rho \sim 10^{-29}$ g/ cm^3, a high temperature and is practically fully ionized despite the expansion of the Metagalaxy.* Thus, the encountered assertion that the high temperature of the intergalactic gas is evidence against the evolutionary cosmology with $\rho \simeq \rho_k = 2 \cdot 10^{-29}$ g/cm^3 and in favor of stationary cosmology, appears to be incorrect. At the same time, any cosmological model requires an estimate of the mean density of matter from independent considerations.

At $T \sim 10^5 - 10^6 {}^\circ K$ and $\rho \sim 10^{-29}$ g/cm^3, when the gas is nearly fully ionized and the electron concentration $n_e \sim 10^{-5}$, the detection of such a gas by radiomethods is quite difficult. The absorption of radio waves in the intergalactic gas is determined by the formula [17] :

* As is shown in #2, the ionization of the intergalactic gas is nonequilibrium.

../..

$$\tau \simeq 10^{-2} n_e^2 \cdot T^{-3/2} \nu^{-2} (17.7 + ln \frac{T^{3/2}}{\nu} R . \qquad (39)$$

Even at $R \sim R \simeq 5 \cdot 10^{27}$ cm, $T \sim 10^4 \,^oK$ and $n_e \sim 10^{-5}$ cm^{-3}, the optical thickness $\tau \gtrsim 1$ only at $\nu \lesssim 3 \cdot 10^5$ ($\lambda \gtrsim 1$ km). Without even speaking of the difficulty of receiving such long waves (this is possible, in principle, when using satellites), the effect of intergalactic absorption will be concealed by absorption within the bounds of the Galaxy (for example, at $\nu \sim 3 \cdot 10^5$, $n_e \sim 10^{-1}$ and $T \sim 10^4 \,^o K$, the thickness $\tau \sim 1$ at $R \sim 10^{20}$ cm).

A great interest is offered by the rotation of the polarization plane in the intergalactic magnetic field. Analysis of that effect allows to obtain an important parameter for the Metagalaxy : $M = \langle n_e H \rangle$, proportional to the rotation angle. For example, of the field H in the visual ray of length R varies many times in direction, we have $M \infty R^{1/2}$ [25]. An assumption was brought forth lately, however, that the intergalactic field is quasiuniform and consequently, $M = \langle n_e R \cos \alpha \rangle$, where H is the field intensity and α is the angle between the field and the visual ray. At $\cos \alpha \sim 1$, $n_e \sim 10^{-5}$ and $R \sim 5 \cdot 10^{27}$, the parameter $M \sim 10^{23}$ H. At the same time, as follows from observations, the rotation in the Galaxy and in sources of polarized radio emission contributes $M \sim 10^{14}$. It is possible that this contribution is sometimes even lower, for example, at observation in directions close to the galactic pole. In any case, if the regulated intergalactic field $H_{Mg} \gtrsim 10^{-9}$ oe, this may become noticeable, while measuring the value of M for a series of sources, and determining the statistical dependence of M on their distance and direction (that is, on $\cos \alpha$).

Quite promising appears to be the possibility of detection of hot intergalactic gas by its emission in the X-ray band. Attempts to interpret the recent measurements of X-ray fluxes by intergalactic gas emission in the evolutionary model for $n \sim 10^{-5}$ cm^{-3} lead to temperature $T_p \sim 3 \cdot 10^6 \,^o K$ (the value of T_p is strongly dependent on temperature at earlier stages of evolution of the Universe, (see [28]). Taking into account the possibility of explaining the observed X-ray flux by galaxy emission [29], this value of temperature is the upper limit, and it does not contradict the calculation in #2 of the possible lower limit of temperature of the intergalactic gas, $T \sim 10^5 \,^o K$.

****** THE END ******

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On page 4, line 17 } read "intergalactic" instead of "metagalactic"
" " 9 line 18 }

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